Engineering Economics *Goes Green*

What financing challenges did the first ancient Egyptian engineer face? After setting the table with that interesting scenario, we move on to modern engineering economics. There, calculating the cost of generating one dollar of savings is joined by the value of assessing the oft-overlooked cost of doing nothing. The result is a stronger argument for sustainable building and retrofitting in the contemporary age, and that's no pyramid scheme.

BY LARRY CLARK, LEED® AP

Simple payback might have, in the past, been effective in justifying engineering projects. However, with today's availability of widely diverse energy-savings initiatives, more sophisticated tools may be needed if we're to do a reliable and credible economic analysis of an energy-savings project.

Going back to ancient Egypt, many historians believe that Imhotep was the first engineer (and architect), since he is credited with designing the Step Pyramid for the Pharaoh Djoser in the 27th century BC. It is unlikely, however, that engineering economics was a part of the process on that particular project, since its budget — if one existed — does not seem to have been recorded. However, when the Great Pyramid was built a century later, its cost of 1,600 talents was noted. Depending upon whether these were gold or silver talents, that project in today's dollars would likely be in the range of $50 million to nearly half a billion U.S. dollars.

And, although the concept of "interest" was apparently recognized by then (in 2000 BC, the Babylonians paid interest on the grain they borrowed[1]), it is probably a safe assumption that the project was "pay as you go," particularly since there's very little chance of an ROI from a tomb! Or is there? Perhaps Cheops' son, Radjedef, put in a fast-food franchise and started selling tours of Dad's tomb …

If that were the case, what would the economics of the enterprise have looked like? If we examine the most basic model of simple payback, with cash flow coming entirely from tour ticket revenues — without any regard to operating or maintenance costs, the time value of the money (assuming they had actual money then, which is problematical); or risk — and we assume that: (1) the price of admission is one 3,600th (1/3,600) of a talent (equivalent to a Babylonian shekel, with apologies to academia) and (2) an expected average attendance of 10,000 visitors a day, 365 days a year, then the model would look like:

- Cash flow =1 shekel/person x 10,000 persons/day x 365 days/year = 3.65 million shekels/year or (dividing by 3,600) 1,013.89 talents/year
- Payback period=1,600 talents/1,013.89 talents/year = 1.58 years

This model is, of course, very simplistic. It does, however, point out a significant limitation of simple-payback analysis, which is its inability to compare different solutions on an "apples to apples" basis or to other potential investments (uses of the same money) or even to not making any investment. That may not have been a problem in ancient Egypt, but in today's business environment, more precise tools are obviously required, and simple payback is more typically used on discrete capital projects with clearly defined operational savings.

The challenges of the ancient engineers — perhaps even through the time of da Vinci and his Renaissance colleagues — were far more technical than economic. That probably changed with the Industrial Revolution, and today the study of engineering economics is a frequently required part of an undergraduate engineering curriculum and one of the subjects covered on the Fundamentals of Engineering (FE) examination.[2] And in reality, the economic hurdles facing an engineering project today are often more daunting than are the technical obstacles. Any engineer who's had to "sell" a high-first-cost project to a recalcitrant client, or to his or her top management, knows this to be fact.

ECONOMICS AND ENERGY EFFICIENCY

So what, exactly, is engineering economics and how is it specifically applicable to energy-efficiency projects, particularly those whose costs are mostly "soft"? According to one definition, "Engineering economics, previously known as engineering economy, is a subset of economics for application to engineering projects. Engineers seek solutions to problems, and the economic viability of each potential solution is normally considered along with the technical aspects."[3] Watts and Chapman go on to say that, "The role of engineering economics is to assess the appropriateness of a given project, estimate its value, and justify it from an engineering standpoint."[4]

One would correctly expect, then, that engineering economics would rely heavily on recognized financial concepts such as present and future values, discrete compounding, and discount factors, and that the challenge of justifying the cost of an energy-efficiency project would depend largely on the ability to accurately predict the energy savings. This has resulted in the development of some interesting ways of examining these issues.

For example, in his work on energy systems in agriculture and biomass fuel production, Professor Bryan Jenkins at UC Davis has developed a revenue-requirements approach to determining the energy revenues required to earn a desired ROI.[5] And Christopher Russell has pioneered the concept of energy volume at-risk and the annualization of project costs to account for the useful economic life and time-value of the investment.[6]

According to Russell, if the formula for Capital Recovery Factor – which is the reciprocal of Uniform Series Present Worth (P/A,i,n), where P equals present value, A equals constant annuity, "i" equals interest rate, and "n" equals number of periods — is used, with i now representing the cost of capital or discount rate on future cash flows and n representing the useful economic life (in years) of the proposed solution (energy improvement project), then

$$CRF = A/P = \frac{i(1+i)^n}{[(1+i)^n]-1}$$

This model allows an annualized cost analysis and for a capital project involving equipment having a predictable useful economic life (n), it works well. For example, if a 10-year-old, low-efficiency, 13-ton packaged rooftop unit were to be replaced with a new, high efficiency RTU, the model might look like this:

- Total installed cost of project = $25,000
- Useful economic life of RTU = 20 yrs
- Internal cost of capital = 6%
- Current cost of energy = $0.08/kWh and $12.50/kW demand = $0.10/kWh average
- Energy consumed by old RTU = 131,659 kWh/yr
- Energy consumed by new RTU = 77,699 kWh/yr
- Energy saved = 131,659-77,699 =53,960 kWh/yr

Therefore, from the formula above

$$CRF = \frac{.06(1+.06)^{20}}{[(1+.06)^{20}]-1} = 0.087$$

The annualized cost to save 1 kWh would be:

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$$\frac{\text{Project cost x CRF}}{\text{Energy saved}} = \frac{\$25{,}000 \text{ x } .087}{53{,}960} = \$0.04$$

The cost-to-benefit ratio, then, would be

$$\frac{\text{Cost to save 1 kWh}}{\text{Current cost of energy}} = \$.04/\$.10 = 0.40$$

In other words, an investment now of 40 cents will avoid an energy cost of one dollar.

THE COST OF DOING NOTHING

And, conversely, the cost of doing nothing would be:

(Current cost of energy: cost to save 1 kWh) x energy saved = ($.10/kWh - $.04/kWh) x 53,960 kWh/yr = $3,238/yr x 20 years = $64,760 in wasted energy costs

Contrast that to the simple payback, payback period:

$$\frac{\text{Project cost}}{\text{Cost of energy saved}} = \$25{,}000/(\$.10/\text{kWh x } 53{,}960 \text{ kWh/yr}) = 4.6 \text{ yrs}$$

With a payback of approximately 25% of the life of the equipment, this project might still be undertaken, but the economic model is not nearly as compelling.

Taking this process one step further, if we consider n to be the expected continued occupancy of a facility, we can use this model to evaluate the costs of energy improvement solutions having an undefined or indefinite useful economic life (e.g., software that is provided with continuous upgrades) or solutions having a life expectancy that is longer than the contemplated occupancy or lifetime of the facility itself.

In this case, the cost of doing nothing is particularly significant, since a new LEED®-certified commercial building may have a design life expectancy of 100 yrs.[7] This model also gives us the flexibility of evaluating the true value of upgrading/replacing equipment based on the incremental efficiency improvements in that type of equipment that may occur early in the product's projected economic life. With the improvements in design and manufacturing technology making rooftop package units with EERs of 14.311 available today, this becomes an important consideration.

For example, if we take the case of a hospital considering the implementation of building oversight management, there is no finite useful economic life of the solution and there is no "equipment" involved. The solution is, rather, a process — a combination of an advanced monitoring capability (software) with a method for managing real-time energy costs. This is accomplished by hosting the data (collected by the software process) in an operations center staffed by experienced engineers.[8]

If we assume a total first cost (initial implementation plus monthly monitoring for the first year) of

- \$147,000 (project cost)
- Occupancy of the present facility anticipated to be another 10 years min. (n)
- Internal cost of money = 6.5% (i)
- Current cost of energy = \$0.11/kWh
- Expected energy savings = 1,463,173 kWh/yr

Using our model

$$CRF = \frac{0.065(1+.065)^{10}}{[(1+.065)^{10}]-1} = 0.14$$

Annualized cost to save 1 kWh: $$\frac{\$147{,}000 \times .14}{1{,}463{,}173} = \$0.014$$

Cost/benefit = \$0.014/\$0.11 = 0.13

In this case, an investment of thirteen cents avoids one dollar in energy cost. Although the simple payback is less than one year regardless of the expected occupancy or cost of capital, the ongoing economic penalty for not doing the project is clearly demonstrated and compared using this approach. Based on the variables used above, the cost of not implementing the project is \$385/day for the next 10 yrs, or >\$140,000 in unnecessary energy costs.

(\$.11/kWh - \$.014/kWh) x 1,463,173 kWh/year = \$14,046/yr/365 days/yr = \$385/day

And if we lower the cost of capital or discount rate, or increase the anticipated occupancy period, then the value of the project becomes even more compelling.

And, finally, there are the non-financial economic considerations to be evaluated. Although that sounds incongruous, the implementation of cap and trade carbon credits — although non-financial by definition — has a significant economic impact. And it's reasonable to assume that the U.S. will join the European Union (EU) in imposing such a plan, since — as a visit to President-elect Obama's website will confirm — he has endorsed cap and trade.[9]

The world's largest carbon credit trading system, the EU Emissions Trading Scheme (EU ETS) has shown that although the economic considerations are significant, non-economic considerations form the allocation of the CO_2 allowances.[10] So the decisions to make or buy, replace or repair, are not as simple in a world going green, and tools beyond simple payback are required.

We don't fault Radjedef for not commercializing his Dad's tomb and missing the opportunity of being the greatest entrepreneur of his day, but failing to recognize significant economic opportunities in today's world could make us wish we had a tomb to hide in! **ES**

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